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A NEW BATHYMODIOLINE MUSSEL (BIVALVIA: MYTILOIDEA: MYTILIDAE: BATHYMODIOLINAE) FROM VENT SITES NEAR KUEISHAN ISLAND, NORTH EAST TAIWAN

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***ABSTRACT.* –** A new species of bathymodioline mussel, *Bathymodiolus* (sensu lato) *taiwanensis*, new species, is described from hydrothermal vents in rather shallow water (200–355 m) near Kueishan Island (Turtle Mountain Island) off the northeast coast of Taiwan, on the Okinawa Arc. The new mussel belongs to the *Bathymodiolus* (sensu lato) *childressi* clade which is characterized by a so-called "multibundle" foot-byssus retractor muscle complex and subterminal to terminal umbones. With a length of up to 56 mm, *B.* (sensu lato) *taiwanensis*, new species, is the smallest bathymodioline mytilid yet known.

***KEY WORDS.* –** Hydrothermal vents, Taiwan, Mollusca, Bivalvia, Mytilidae, *Bathymodiolus*, new species, taxonomy.

INTRODUCTION

Large mussels of the subfamily Bathymodiolinae form an important and characteristic part of the faunal communities of numerous hydrothermal vents, cold seeps, warm seeps, hydrocarbon seeps or submarine volcanoes in the deep sea between about 200 m and more than 3,000 m depth. Twenty one species in three genera are described and named to date (Kenk & Wilson, 1985; Cosel et al., 1994; Hashimoto & Okutani, 1994, Cosel & Olu, 1998, Gustafson et al., 1998, Cosel et al., 1999, Hashimoto, 2001, Cosel, 2002, Cosel & Marshall, 2003, Okutani et al., 2004 [2003], Hashimoto & Yamane, 2005, Hashimoto & Furuta, 2007), Their size ranges from 58 mm (*Tamu fisheri* Gustafson, Turner, Lutz & Vrijenhoek, 1998) to 360 mm (*Bathymodiolus boomerang* Cosel & Olu, 1998). Other bathymodioline mussels are still awaiting description and are currently under study. In this paper, a species smaller in size than *Tamu fisheri* is described from hydrothermal vents off NE-Taiwan.

The first scientific exploration of the Tashi fishing ground off the northeastern coast of Taiwan near Kueishan Island (Turtle Mountain Island) took place in May 2001 on board the chartered commercial trawler JIN TUNG LONG No. 26 (for details and description of the site, see Bouchet & Cosel, 2004). In this tectonically active region which forms part of the Okinawa Arc (Jeng et al., 2004), close to the very shallow hot vents near the shore line of Kueishan Island (Ng, Huang & Ho, 2000), other hot vents were discovered in depths of 200–355 m. These were found hosting a small fauna of probable chemosymbiotic taxa including the giant lucinid bivalve *Meganodontia acetabulum* Bouchet & Cosel, 2003, large lucinid species of the genus *Lucinoma* (described by Cosel & Bouchet, 2008, in press), and a small mussel taken on blocks of a sulphur compound. In contrast to vents elsewhere, typical vent limpets have not been encountered at Tashi. The crab *Xenograpsus testudinatus* Ng, Huang & Ho, 2000, was collected at the nearby hot vents in shallower water (Ng et al., 2000) where it feeds on dead zooplankton that rains down from the hot sulphurous plumes of these vents (Jeng et al., 2004). The small mussel found on the vent areas of the Tashi fishing ground, was initially thought to be a species of *Idas*. However, after examination of shell and internal features, especially the foot-byssus retractor muscle complex, it proved to be an undescribed species in the subfamily Bathymodiolinae within the "*Bathymodiolus*" *childressi* clade (Jones et al., 2005). It is provisionally placed in the genus *Bathymodiolus* (in the large sense).

MATERIALS AND METHODS

The following abbreviations are used: lv, left valve; rv, right valve; sh, shell with both valves; spm, for live-collected specimen; v, single valve. Specimen repositories are: Muséum national d'Histoire naturelle, Paris (MNHN), National Museum of Natural Sciences Taichung, Taiwan (NMNS), National Museum of New Zealand Te Papa Tongarewa,

Wellington (NMNZ), National Science Museum Tokyo, Japan (NSMT), Zoological Reference Collection of the Raffles Museum, National University of Singapore (ZRC).

TAXONOMY

MYTILIDAE Rafinesque, 1815

Bathymodiolus Kenk & Wilson, 1985

Bathymodiolus Kenk & Wilson, 1985: 255

Type species. – *Bathymodiolus thermophilus* Kenk & Wilson, 1985, by original designation.

Bathymodiolus (sensu lato) *taiwanensis*, new species
(Figs. 1A–K, 2A–I, 3A–L, 4A–D, 5A–C, 6A–C, 7A–C, 8A–D)

Idas sp. – Bouchet & Cosel, 2004: 705.

Type material. – Holotype (reg. no NMNS-5912-001) NMNS Taichung, 48.7 mm, Tashi fishing ground, NE coast of Taiwan near Kueishan Island (Turtle Mountain Island); 24°49.85'N 121°59.99'E, 271 m, taken by local trawler, 23 Aug.2007, coll. Tin-Yam Chan. Paratypes: same locality, 7 paratypes in NMNS, NMNS-5912-002 to 5912-00 8; 2 paratypes in NMNZ, 13 paratypes in MNHN (MNHN 20964) and 2 paratypes in NSMT ; 1 paratype in ZRC.MOL.2845, 24°50.8'N 121°59.9'E, 281 m, TAIWAN 2001 stn. CP 113.

Other material examined. – Tashi fishing ground, NE coast of Taiwan, 24°50.5'N 121°59.9'E, 205 m, TAIWAN 2001 stn. CP 81, 76 spm, 4 sh, 4 v + fragm., 8 May 2001, all MNHN. Same locality, 24°50.8'N 121°59.9'E, 281 m, TAIWAN 2001 stn. CP 113, 75 spm, 21 May 2001, all MNHN. Tashi vent area (no precision), 200–355 m, 1 spm., 2 sh, 1 v. coll. Tin-Yam Chan, 12 Jul.2005, MNHN.

Description. – Shell rather small for a bathymodioline mussel, only 40 to 56 mm long, rather light but strong, quite variable in outline, rather elongate-modioliform, straight to slightly curved dorsoventrally, moderately inflated, most so just in front of the middle, equivalve, length/height ratio 2.3–2.6. Valves gradually becoming higher posteriorly, highest point between the second and the third third of the shell or somewhat more anterior. Beaks slightly subterminal to almost terminal, in adult specimens leaving only a very short anterior part of about 1–4 mm in front of the umbones. Anterior margin narrowly but evenly rounded; ventral margin almost straight to more or less concave in the anterior half. Posterior margin evenly rounded in its ventral part, convex dorsally; postero-dorsal angulation rounded to indistinct, situated above the posterior part of the posterior retractor scar.

Ligament plate slightly convex, often more so in its anterior part. Shell exterior with well-marked, irregular growth lines and very fine and faint radial striae or vermiculations, only visible under a lens and slightly visible on the interior . Umbo very broad and flattened. Very old specimens eroded on the umbonal and median part and periostracum persistent only close to the margin.

Periostracum thick, hard, dark brown to almost black, smooth, glossy to somewhat dull, sometimes with irregular co-marginal folds not reflected on the chalky surface, often eroded in the umbonal region. Surface frequently covered with byssal endplates of other specimens; occasionally-triangular byssal bristles irregularly fixed to the shell surface and rather densely spaced but not so "regular" as byssal bristles on other modioline species.

Hinge toothless, anterior hinge margin almost not broadened towards ventrally. Ligament opisthodetic, strong, extending over half of the length of the posterior part of the shell and ending abruptly posteriorly. Ligamental plate in gerontic specimens often "secondarily" thickened. Subligamental shell ridge very thin to indistinct. Anterior adductor scar small, somewhat circular, situated just under the umbo. Posterior adductor scar rather large, united with the posterior-most scar of the posterior pedal and byssus retractor muscle complex; anterior scar of the same complex usually separated from it, elongated and situated under the posterior-most part of the ligament. Occasionally, both retractor scars appear united, forming one long scar. Anterior byssus retractor muscle scar situated in the posterior part of the umbonal cavity, visible only from ventral perspective. Pallial line parallel to ventral margin, straight or slightly concave.

Shell beneath periostracum dull-whitish, internally nacreous, on the dorsal part with a pinkish hue.

Animal with long and fleshy ctenidia, in a 50 mm specimen 37 mm long and about 6.5 mm broad; outer and inner demibranchs of equal length. Demibranchs in a 51.3 mm specimen about 0.6 mm thick. Ascending lamellae of outer demibranch anteriorly fused to the mantle for a very short distance, those of the inner demibranch being fused to the visceral mass. Food-groove very shallow and narrow.

Inner mantle folds separate along the entire length of the ventral margin length from in front of the anterior adductor to the posterior margin, edges extremely frilled and undulate on the posterior part under the posterior adductor for a length of about 12 mm in the 50 mm spm, towards the anterior only slightly frilled. At the anterior, inner mantle folds terminating over the anterior adductor and folding back directly onto the muscle but not visibly continuing transversally over it to meet the mantle fold of the opposite side. Valvular siphonal membrane short and thin, without median papilla, however, in some spms, a vestige of papilla is visible.

Foot slender, more or less pointed, about 12 mm long (byssus orifice included) in the specimen of 50 mm shell length. Foot-byssus retractor muscle complex somewhat variable, in comparison to other bathymodioline mussels moderately elongated as is the shell (Figs. 5–7); anterior retractor long, attached to the shell in the posterior part of the long umbonal cavity, with the anterior-most part in or just behind the middle of the cavity. Posterior pedal

Fig. 1. *Bathymodiolus* (sensu lato) *taiwanensis*, new species, Tashi vent area, 24°49.85'N 121°59.99'E, 271 m, taken by fishing boat, 23 Aug.2007: A–C, holotype NMNS (48.7 mm); A, exterior of rv; B, interior of rv; C, exterior of lv; D–F, paratype MNHN (48.8 mm). D, exterior of rv; E, ventral view; F, interior of rv; G–H, paratype I NMNS (45.3 mm). G, exterior of rv; H, interior of rv; I–K, paratype NMNS (48.5 mm). I, exterior of rv; J, exterior of lv; K, dorsal view.

Fig. 2. *Bathymodiolus* (sensu lato) *taiwanensis*, new species: A–B, Tashi vent area, 24°49.85'N 121°59.99'E, 271 m, taken by fishing boat, 23 Aug.2007. A, exterior of lv; paratype I NMNS (45.3 mm); B. exterior of lv, paratype MNHN (48.4 mm). C–I, Tashi vent area, 24°50.5'N 121°59.9'E, 205 m, stn. CP 81, TAIWAN 2001 cruise, 8 May 2001. all MNHN. C, exterior of rv; D, interior of rv; E, interior of lv; F, exterior of lv (50.2 mm). G, exterior of rv; H, exterior of lv; I, interior of lv (53.1 mm).

Fig. 3. Bathymodiolus (sensu lato) taiwanensis, new species: Tashi vent area (no coordinates), 200–355 m, coll. T.-Y.Chan 12 Jul.2005, MNHN: A, exterior of rv (53.0 mm); B, interior of rv (53.0 mm); C, exterior of rv (40.1 mm); D, interior of rv (40.1 mm); E–J, juvenile specimens, Tashi vent area, 24°50.8'N 121°59.9'E, 281 m, stn. CP 113, TAIWAN 2001 cruise, 21 May 2001, all MNHN; E, exterior of lv; F, interior of rv (30.8 mm); G, exterior of rv; H, dorsal view (30.3 mm); I, exterior of lv (26.2 mm); J, exterior of lv (26.1 mm). K–L, specimen with byssal bristles, 24°50.5'N 121°59.9'E, 205 m, stn. CP 81, TAIWAN 2001 cruise, 8 May 2001, MNHN. K, exterior of lv (45.6 mm); L, close-up view of the byssal bristles.

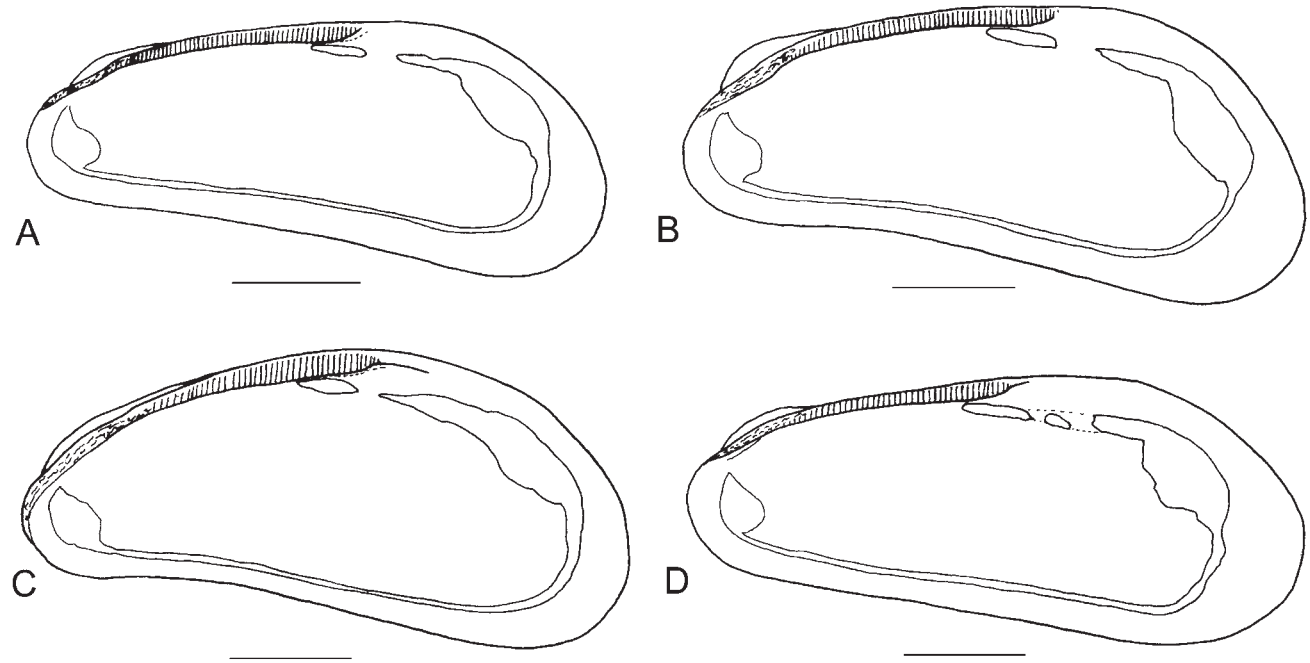

Fig. 4. A–D. *Bathymodiolus* (sensu lato) *taiwanensis*, new species, semi-schematic drawings of the interiors of rv: A, paratype NMNS (45.3 mm); B, specimen from CP 81, TAIWAN 2001 cruise (50.2 mm); C, paratype MNHN (48.8 mm); D, specimen from CP 81 (47.1 mm). Scale bar = 10 mm

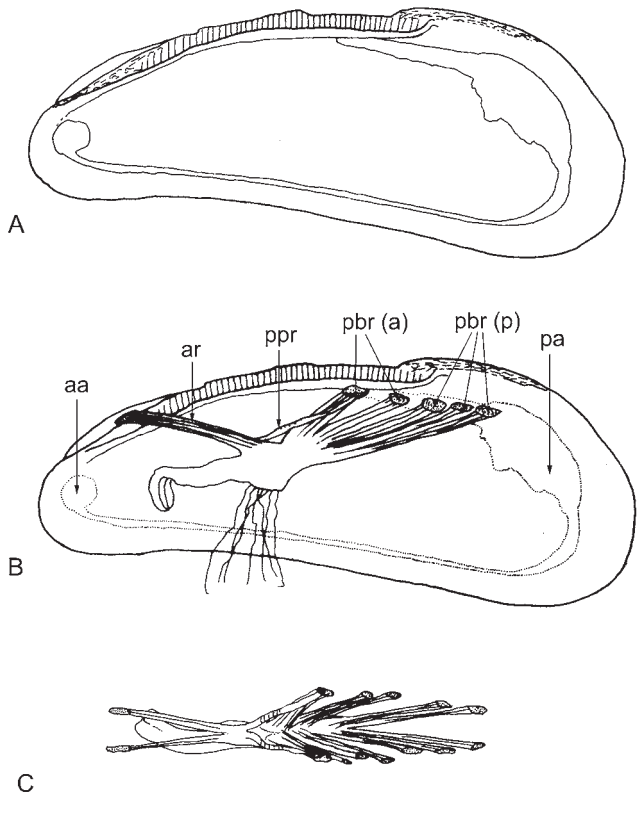

Fig. 5. A–C. *Bathymodiolus* (sensu lato) *taiwanensis*, new species,Tashi fishing ground, TAIWAN 2001 cruise, Stn. CP 113. semi-schematic drawings: A, Interior of rv. B, Foot and byssus retractor muscle complex and its situation in the shell (separate slender strand of anterior retractor serving as support for labial palps not drawn); C, Dorsal view of retractor muscle complex. Shell length 51.8 mm. aa, anterior adductor scar; ar, anterior retractor; ppr, posterior pedal retractor; pbr (a), anterior bundle of posterior byssus retractor; pbr (p), posterior bundle of posterior byssus retractor; pa: posterior adductor scar. Scale bar = 10 mm

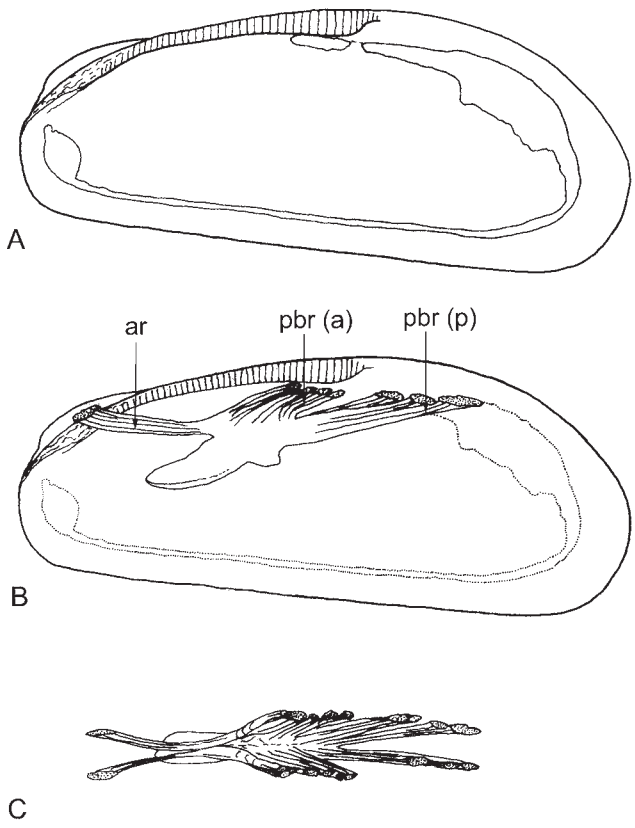

Fig. 6. A–C. *Bathymodiolus* (sensu lato) *taiwanensis*, new species, Tashi fishing ground, paratype MNHN, semi-schematic drawings: A, interior of rv; B, foot and byssus retractor muscle complex and its situation in the shell; C, dorsal view of retractor muscle complex. Shell length 48.4 mm. ar, anterior retractor; pbr (a), anterior bundle of posterior byssus retractor; pbr (p), posterior bundle of posterior byssus retractor. Scale bars = 10 mm

Table 1. Selected measurements of *Bathymodiolus* (sensu lato) *taiwanensis*, new species, with l/h ratio.

Shell dimensions (mm)	l/h ratio	Remarks
56.0 × 23.0 × 18.3	2.4	associated spm MNHN (CP 113)
53.0 × 19.1 × 18.1	2.8	associated spm MNHN (coll. T.Y.Chan)
50.6 × 21.3 × 16.6	2.4	paratype IV NMNS-5912-005 Taichung
48.8 × 22.1 × 19.1	2.2	paratype I MNHN
48.7 × 19.8 × 17.4	2.5	holotype NMNS-5912-001 Taichung
48.5 × 21.6 × 16.3	2.2	paratype VI NMNS-5912-007 Taichung
48.4 × 19.6 × 18.0	2.5	paratype II MNHN
47.1 × 19.9 × 16.6	2.4	paratype ZRC.MOL.2845 (CP 113)
45.3 × 18.4 × 15.6	2.5	paratype I NMNS-5912-002 Taichung
45.3 × 18.0 × 15.4	2.6	paratype VII NMNS-5912-008 Taichung
45.2 × 19.9 × 15.5	2.3	paratype V NMNS-5912-006Taichung
46.0 × 19.6 × 16.5	2.3	paratype II NMNS-5912-003Taichung
45.0 × 17.8 × 15.5	2.5	paratype I NMNZ
44.0 × 18.6 × 14.2	2.4	paratype III NMNS Taichung
44.0 × 18.1 × 14.0	2.4	paratype II NMNZ
43.8 × 18.4 × 16.4	2.4	paratype I NSMT
39.0 × 16.1 × 12.4	2.4	paratype II NSMT

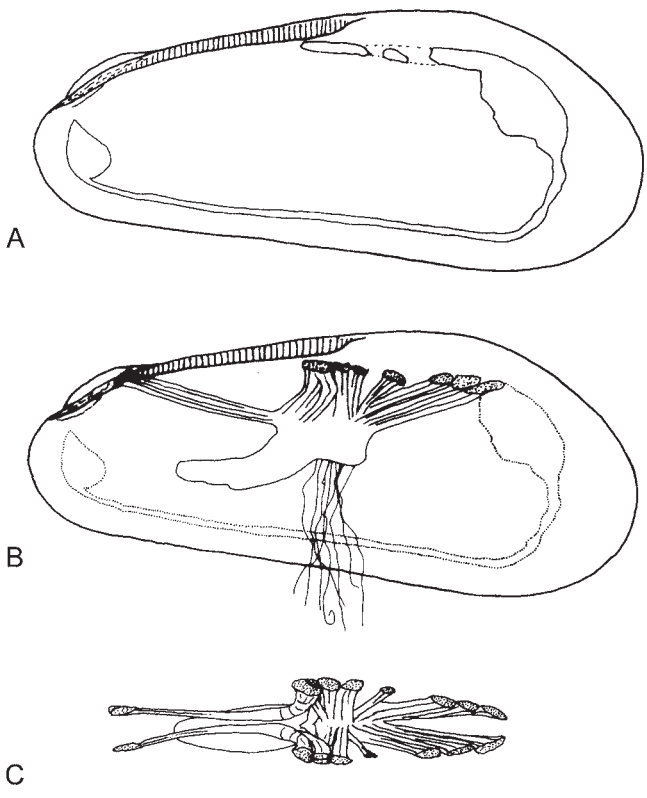

Fig. 7. A–C. *Bathymodiolus* (sensu lato) *taiwanensis*, new species, Tashi fishing ground, TAIWAN 2001, stn. CP 81. Semi-schematic drawings: A, interior of rv; B, foot and byssus retractor muscle complex and its situation in the shell; C, dorsal view of retractor muscle complex (for explanations, see on Fig. 5). Shell length 47.1 mm). Scale bars = 10 mm.

retractor thin to rather thick and anteriorly with a few slight transversal grooves. Posterior byssus retractor comprising several diverging muscle bundles with common base at the base of the byssus. Anterior part of it attached to the long scar at about the middle of the valves, sometimes at almost a right angle (anterior-most bundle) and at about 80° and 70° to the longitudinal shell axis (second and third bundle, Fig. 5), in other specimens more inclined towards posterior. Posterior part of about the same length as the anterior retractor or only slightly longer, passing towards one long attachment point directly in front of that of the posterior adductor. In some specimens bundles of anterior and posterior part in a very short distance, which results in a long, uninterrupted scar (Fig. 5). Posterior pedal retractor muscle rather thin, arising from the anterior side of the foot base behind the base of the anterior retractor muscles, passing towards the anterior bundle of the posterior byssus retractor, reaching the shell inside closely appressed to the bundle a short part of its length only (Fig. 5).

Labial palps strong, palps of the anterior pair narrow-triangular, about 2 mm long in the 50 mm specimen; palps of posterior pair, long and narrow-triangular, 5 mm long in the 50 mm specimen.

Stomach situated just behind the middle of the anterior half of shell length, rather large, with length of 6.5 mm in a 49 mm specimen with rather thick walls and a distinguishable anterior chamber; posterior chamber longer and broader. No entrances of digestive diverticula detected on the inner surface (presumably artefact of preservation). On the posterior left side, a shallow depression corresponds to left pouch. Stomachs observed filled with some mucus and sediment grains. Midgut running posteriorly straight and medially

from the stomach to under the ventricle, bending upwards and entering ventricle in a vertical S-curve. Behind the heart, intestine passing over the posterior adductor and towards ventrally on its posterior side, anus at mid-diameter of posterior adductor.

Heart small and narrow, situated in the posterior half of shell, anterior extremity of ventricle just behind mid-shell/mantle. Auricles long, fused posteriorly in front of the posterior adductor and extending forwards in narrow lobes to the middle of the anterior part of the posterior foot byssus retractor.

***Biotope.* –** Byssally attached to hard substrates. It has been found on blocks of a sulphur compound and also on old pieces of fishing nets on the ground, where it forms dense clusters and agglomerations near hot venting. Biotope and accompanying molluscan fauna are described by Bouchet & Cosel (2004).

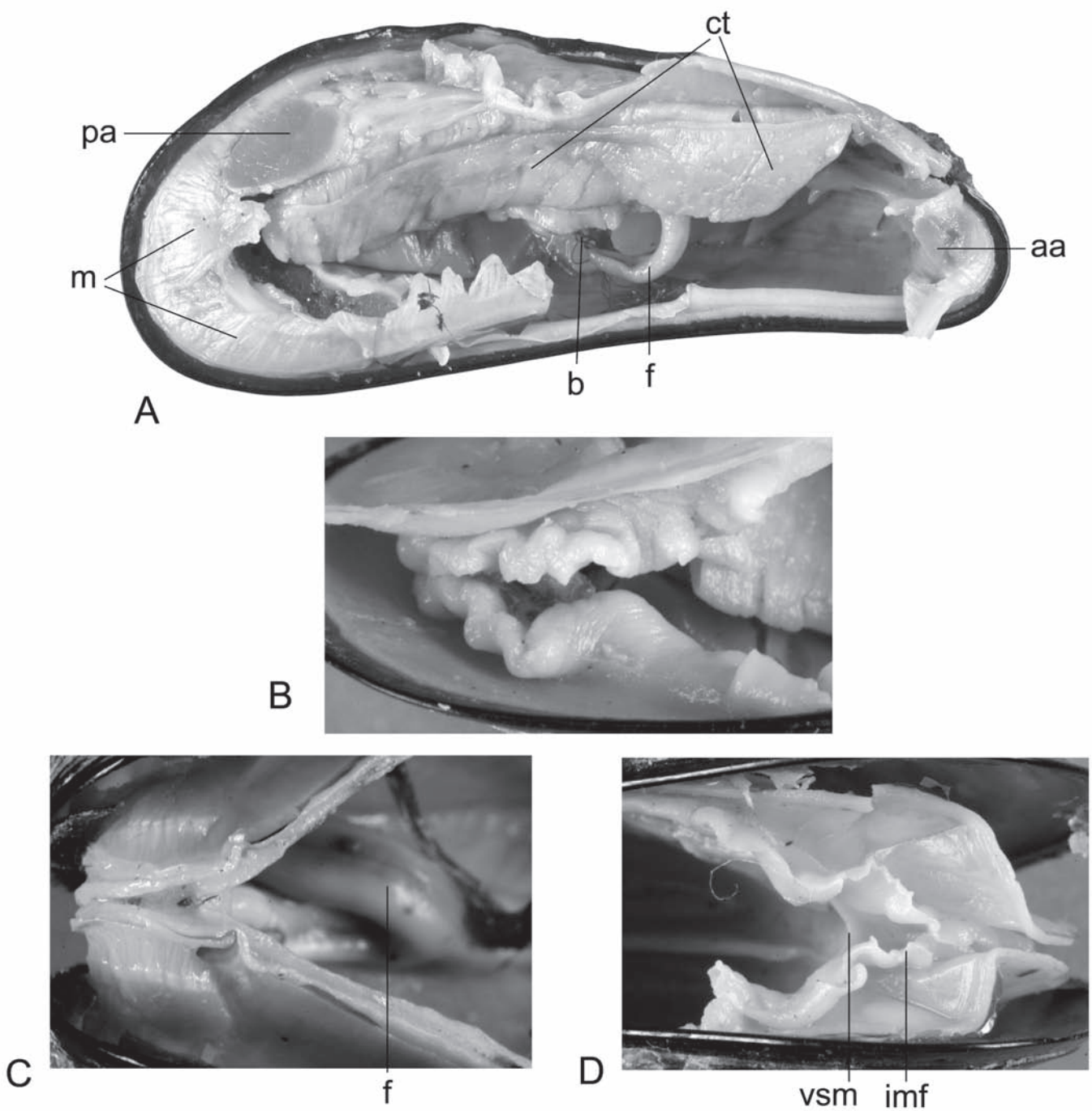

Fig. 8. A–D *Bathymodiolus* (sensu lato) *taiwanensis*, new species, Tashi fishing ground, TAIWAN 2001, stn. CP 113. Gross anatomy: A, Situs, rv removed, right mantle partly removed. aa: anterior adductor, pa: posterior adductor, ct: ctenidia, f: foot, b: byssus, m: mantle. Note the small foot. Shell length 51.3 mm; B, Same specimen, ventral view of posterior part showing the strongly frilled inner mantle fold; C–D. Another specimen, ventral view of (C) anterior and (D) posterior mantle fusion; F, foot, vsm: valvular siphonal membrane. Shell length 43.9 mm.

***Distribution.* –** Only known from the vent area on the Tashi fishing ground at Kueishan Island, NE-Taiwan, between ca. 200 and 350 m depth.

***Etymology.* –** Named after the island of Taiwan, where the type locality is situated.

DISCUSSION

The known species of bathymodioline mussels belong to two well-defined main groups or clades: the *B. thermophilus* clade and the *B.* (sensu lato) *childressi* clade (Cosel, 2002; Jones et al., 2005, Jones & Vrijenhoek 2006). Their principal difference lies in the anatomy of the foot-byssus retractor complex: the posterior retractors of the *B. thermophilus* clade are rather simple with two well separate muscle bundles (see Cosel et al., 1994, Cosel et al., 1999), whereas the *B.* (sensu lato) *childressi* clade is characterized by a so-called multibundle posterior retractor complex. Moreover, the *B.* (sensu lato) *childressi* clade is distinguished from the members of the *B. thermophilus* clade by subterminal to terminal umbones in comparison to the total shell length, whereas in the *B. thermophilus* clade (e.g., *B. thermophilus*, *B. brevior* Cosel, Métivier & Hashimoto, 1964 and *B. boomerang* Cosel & Olu, 1998) the umbones are generally somewhat more backward placed, leaving a well distinguished anterior part.

From morphological evidence, this small bathymodioline mussel can be placed in the *B. childressi* clade. This was first introduced as the *childressi* group by Cosel (2002) in a first grouping of the hitherto known bathymodioline mussels, based on morphology only. Subsequent molecular research confirmed this, and based on this, the *B. childressi* clade was defined by Jones et al. (2005) and Jones & Vrijenhoek (2006). *Bathymodiolus* (sensu lato) *taiwanensis*, new species, is not a *Bathymodiolus* "in the strict sense" and, like the other members of the *B.* (sensu lato) *childressi* clade, will eventually receive a new generic name. The new species is most similar to the separate *B.*(sensu lato) *tangaroa* informal subgroup within the *B.* (sensu lato) *childressi* clade (Jones & Vrijenhoek, 2006) and is for the moment placed therein pending molecular research. The *B.* (sensu lato) *tangaroa* subgroup comprises *B.* (sensu lato) *tangaroa* Cosel & Marshall, 2003 from NE New Zealand, an undescribed geographical subspecies from Edison Seamount, Papua-New Guinea (Cosel & Janssen, in press) and *B.* (sensu lato) *securiformis* Okutani, Fujikura & Sasaki, 2003 from Kuroshima Knoll, Japan. With these, *B.* (sensu lato) *taiwanensis*, new species, shares the more or less elongate shell outline, the narrowly rounded anterior margin and the long and shallow umbones in combination with the multi-bundle foot-byssus retractor complex. However, apart from its very small size, *B. taiwanensis*, new species. is distinguished from *B. tangaroa* by the more forward-placed umbones, the shorter ligament, the longer anterior foot-byssus retractor, the more thick-walled and longer stomach in comparison to shell length and the marked S-curve of the intestine before its passage through the ventricle. With these differences, *B. taiwanenesis*, new species, appears to be the most derived species within the *tangaroa* subgroup. The other informal subgroups within the *B.* (sensu lato) *childressi* clade are the *childressi* group itself, the *hirtus* group with *B.* (sensu lato) *hirtus* Okutani, Fujikura & Sasaki, 2003 and an undescribed species from Edison Seamount (Cosel & Janssen, in press) and the genera *Gigantidas* Cosel & Marshall, 2003 and *Tamu* Gustafson, Turner, Lutz & Vrijenhoek,1998. The byssal bristles seen on some specimens of *B. taiwanensis*, new species, are remininiscent of the bristles of the *B.* (sensu lato) *hirtus* subgroup but are not so regular as on that subgroup and often occur only scattered or are absent. For more details, see Cosel & Janssen (in press).

The 200–355 m depth range of *B.* (sensu lato) *taiwanensis*, new species, is the shallowest in comparison to the other members of the *tangaroa* subgroup: about 640 m (*B.* (sensu lato). *securiformis*), 920–1,205 m (*B.* (sensu lato) *tangaroa*) and ca. 1,600 m (*B.* (sensu lato) *tangaroa* subsp. from Edison).

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